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COMPUTATIONAL MODEL PREDICTION AND BIOLOGICAL VALIDATION USING SIMPLIFIED MIXED FIELD EXPOSURES FOR THE DEVELOPMENT OF A GCR REFERENCE FIELD

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Multi-scale Biophysics Model

Geant4

Particle transport with atomic and nuclear fragmentation processes



RITRACKS

Detailed track structure and energy deposition in microscopic volumes



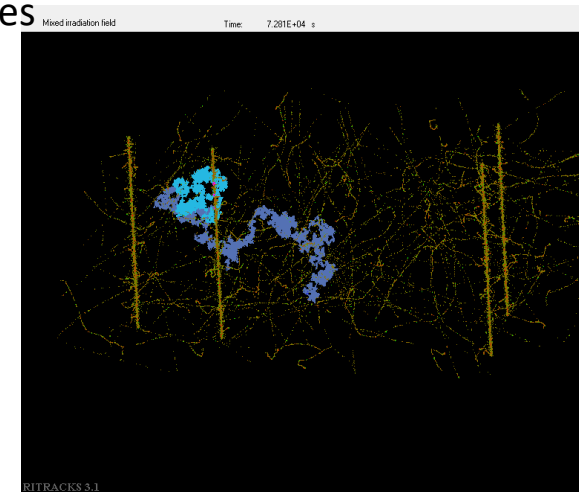
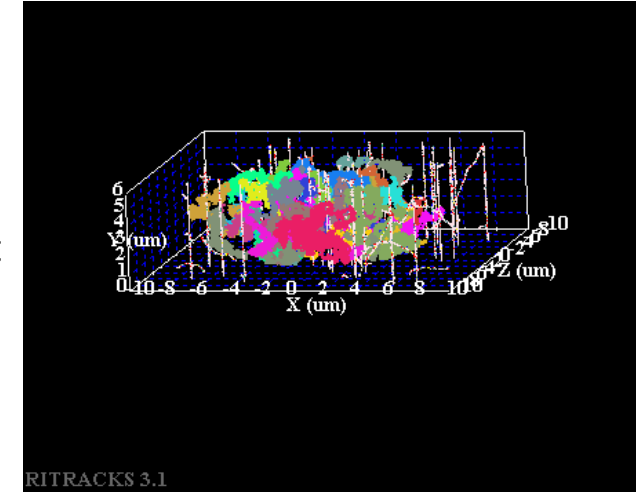
BDSTRACKS

Damage and repair modeling in cells leading to chromosome aberrations

RITCARD

Damage and repair modeling in cells leading to chromosome aberrations

- Full simulation of particle transport through shield
 - Includes all atomic and nuclear fragmentation processes
 - Main output is fluence and average energy of particles escaping the shield
 - This spectrum of energies and fragments defines a list of “mono-energetic” beams for input into RITRACKS
- Detailed simulation of track structure and energy deposition in microscopic volumes
 - Extended to evaluate a mixture of mono-energetic beams delivered at specific time-intervals
 - Allows direct integration with Geant4 outputs
 - Allows evaluation in mixed field and at various dose-rates
- Model for damage and repair processes in cell leading to chromosome aberrations
 - Significantly improved software verification (BDSTracksV265)
 - Independent re-code of model using modern software engineering practices (RITCARD)
 - ***BDSTracksV265 and RITCARD capable of predicting aberrations in mixed fields at various dose rates***



Funded by NASA (NNX16AR97G)

GCR simulation with mixed beam

A. Quick Beam Switching at NSRL

2 beam mix

H + Si

H + Fe (with Shielding)

3 beam mix

Si + Ti + Fe

4 beam mix

H + He + O + Ti

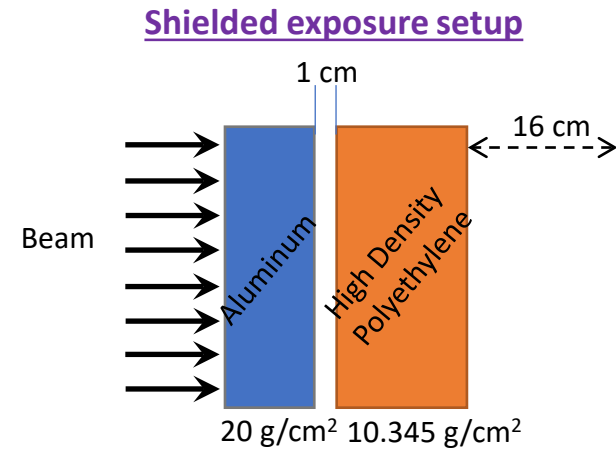
H + He + O + Fe (with Shielding)

6 beam mix

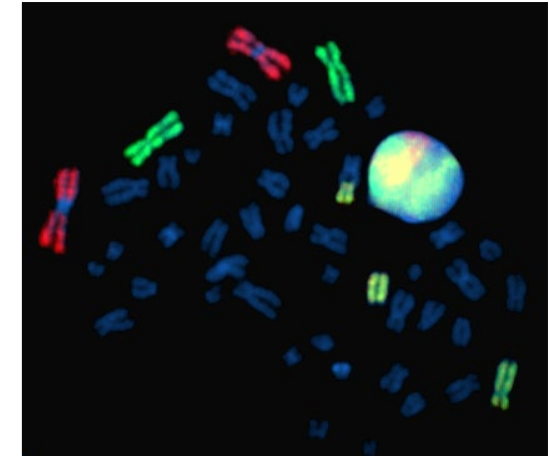
H + He + O + Si + Ti + Fe

Human Fibroblast
Human Epithelial Cell
Human Blood lymphocytes
Mouse Bone Marrow Cells Whole body Exposure)

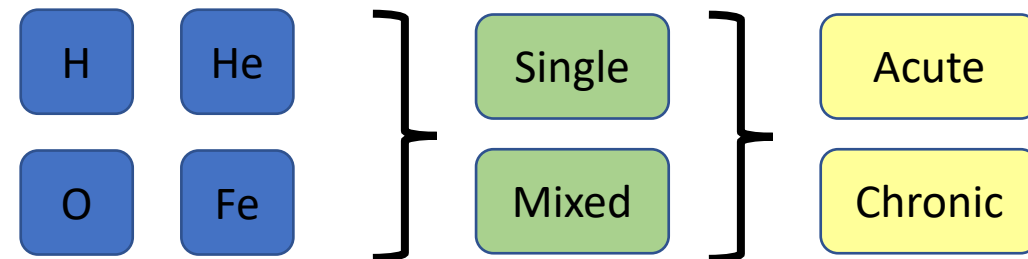
B. Exposure with Shielding



FISH Chromosome Painting



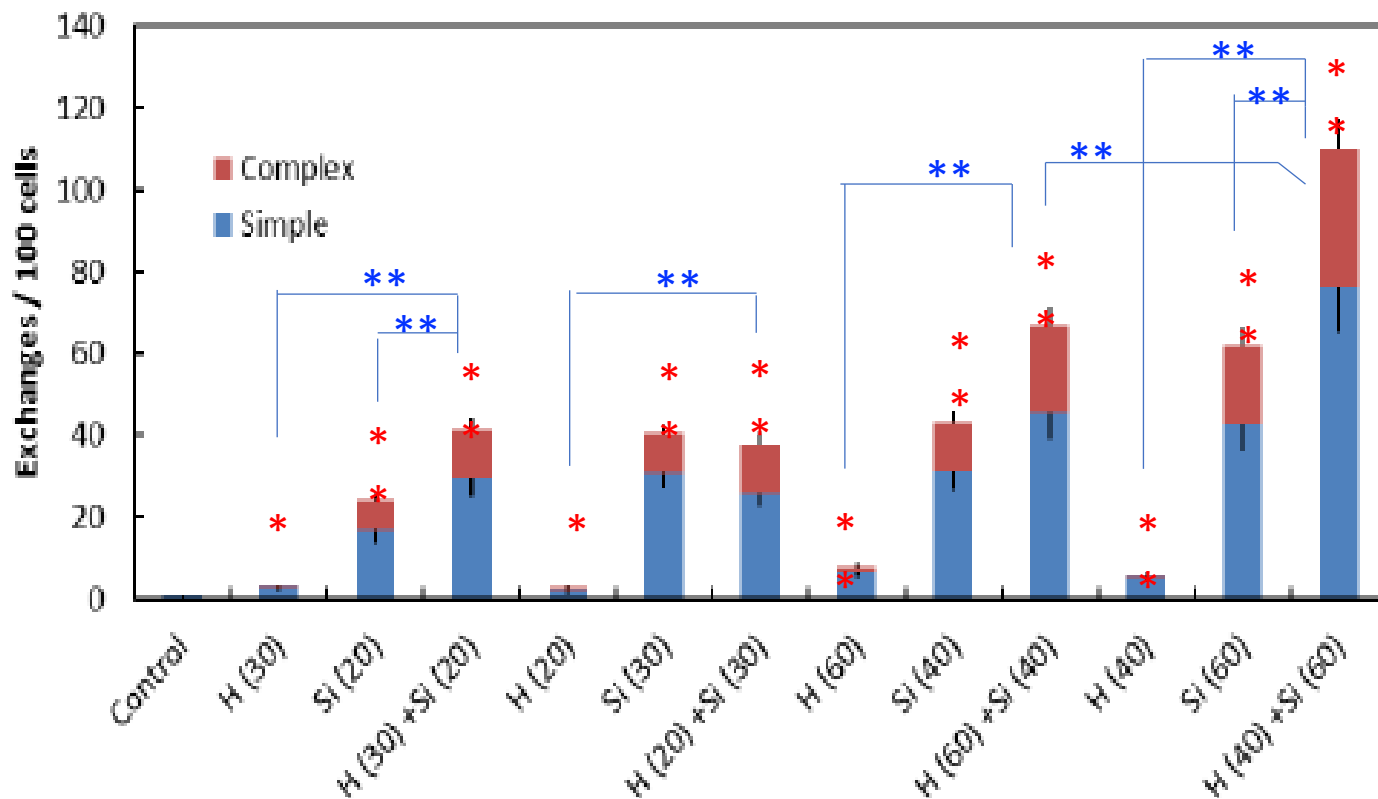
- The “shielded” configuration for experiments and models is closely related to the GCR simulator reference field environment



Funded by NASA (NNX16AR97G)

- There is a possibility of synergism between beams

2-beam Mix (Lymphocytes)



* $p < 0.05$ relative to controls

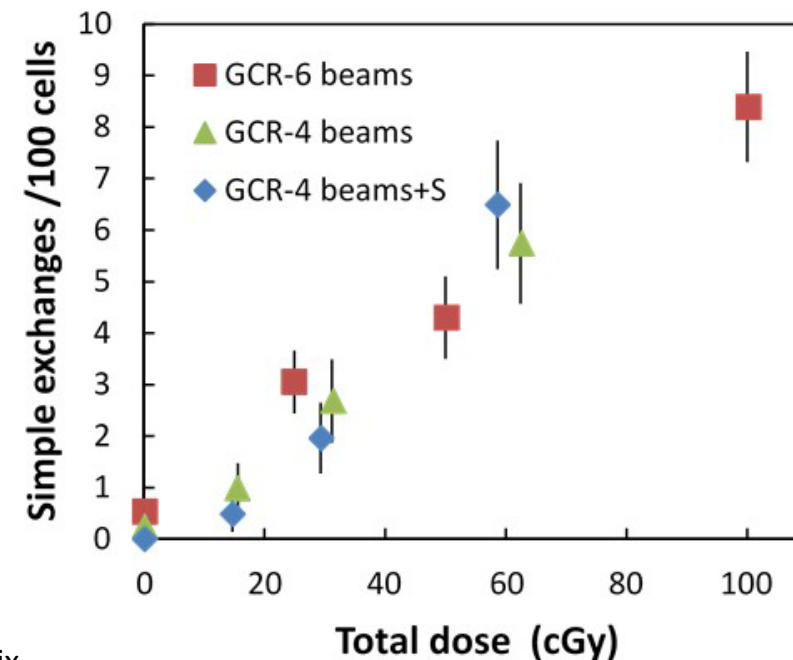
** $p < 0.01$ relative to controls

* $p < 0.05$

** $p < 0.01$

Error bars
indicate standard
error of the mean

GCR simulation 4-beams vs. 6-beams (Fibroblasts)



6 beam Mix

H	(250 MeV)	60%
He	(228 MeV/ μ)	20%
O	(350 MeV/ μ)	10%
Si	(260 MeV/ μ)	2.5%
Ti	(1000 MeV/ μ)	2.5%
Fe	(600 MeV/ μ)	5%

4 beam Mix

H	(250 MeV)	68%
He	(250 MeV/ μ)	20%
O	(350 MeV/ μ)	7%
Ti	(300 MeV/ μ)	5%

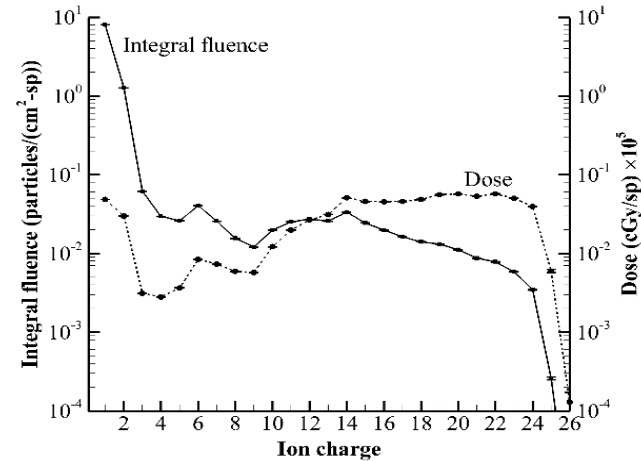
4 beam Mix with shielding

H	(344 MeV)	44%
He	(344 MeV/ μ)	19%
O	(450 MeV/ μ)	24%
Fe	(950 MeV/ μ)	14%

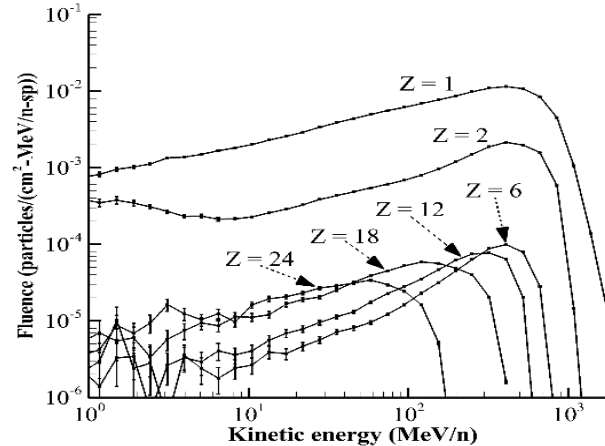
Funded by NASA (NNX16AR97G)

- Modeling is good agreement with experiment of mixed beam condition with shielding

Calculation of particle spectra after shielding by Geant4



Simulated ion-specific integral fluence and dose induced by a 950.0 MeV/n Fe beam incident on the experimental shield configuration.

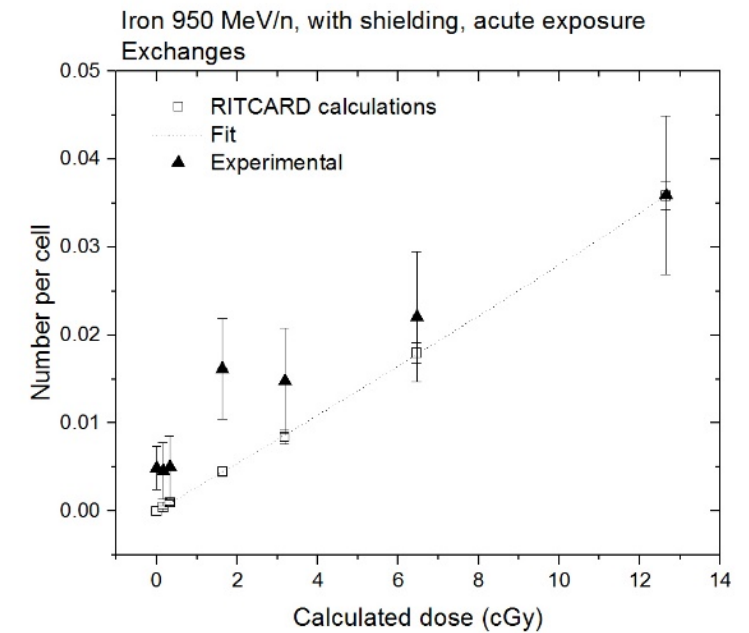


Simulated fluence spectra for Z = 1, 2, 6, 12, 18, 24 ions induced by a 950.0 MeV/n Fe beam incident on the experimental shield configuration.

Upstream and downstream doses (cGy) simulated by Geant4.

Upstream dose (cGy)	Downstream dose (cGy) for 344.1 MeV protons	Downstream dose (cGy) for 950.0 MeV/n Fe
5	4.98	1.54
10	9.96	3.09
20	19.92	6.17
40	39.84	12.34

Frequency of Chromosome Aberrations with Single Beam (Shielded)



Simulation and experimental results of simple exchanges for 950 MeV/ μ iron-ions in human fibroblasts placed 16 cm downstream of a shielding composed by 20.0 g/cm² aluminum and 10.345 g/cm² polyethylene.

Slaba, T.C. et al, Radiat. Res. 2020, 194, 246